



**Figure 1** Centrifuged donor blood

Humans have long recognized the importance of blood, even without understanding the true nature of its role in the body. Modern science has shown that blood is fundamental to life. Blood delivers oxygen and nutrients to, and transports wastes away from, the cells of the body.

## What Is in Blood?

Depending on the size of the individual, the human body contains from 4 L to 5 L of blood. Blood is a connective tissue—a tissue that consists of cells suspended in an intercellular matrix. In humans blood consists of two main components. The cellular component includes red blood cells, white blood cells, and platelets. The intercellular matrix is a yellow-coloured liquid called plasma. The components of blood can be separated by spinning the blood in a centrifuge (**Figure 1**). The densest component—red blood cells—settles to the bottom. The plasma, being the least dense component, rises to the top. The platelets and white blood cells form a thin layer in the middle.

### Plasma

Plasma is a protein-rich liquid in which blood cells and platelets are suspended. Over 90 % of plasma is water. Dissolved or suspended in the plasma are a variety of substances: oxygen, proteins, and nutrient molecules such as glucose, minerals, and vitamins, along with carbon dioxide and other waste products of cellular respiration.

The blood proteins present in plasma include albumins, globulins, and fibrinogen, each of which has a special role. The concentration of albumins in plasma determines the amount of water entering or leaving the bloodstream by osmosis. This helps to balance the amount of water within the body and maintain the appropriate volume of blood. The globulins transport lipids, cholesterol, some fat-soluble vitamins, and some minerals. One type of globulin, the immunoglobulins (or antibodies), are part of the immune response that helps fight many infectious diseases, including bacterial and viral infections. Fibrinogen plays a critical role in blood clotting. Plasma that has fibrinogen and other clotting factors removed is referred to as **serum**.

Plasma also carries a number of dissolved ions:  $\text{Na}^+$ ,  $\text{K}^+$ ,  $\text{Ca}^{2+}$ ,  $\text{Cl}^-$ , and  $\text{HCO}_3^-$ . The components of ordinary table salt, sodium ions ( $\text{Na}^+$ ) and chlorine ions ( $\text{Cl}^-$ ), are the most common ions. Similar to albumin, a high concentration of sodium ions in the plasma creates an osmotic pressure gradient and causes water to enter the bloodstream. As more water enters the blood, the total volume of the blood increases and the blood pressure increases. This helps explain the connection between a high-salt diet and hypertension (high blood pressure).

### Cellular Component

The cellular component of blood consists of red blood cells, white blood cells, and platelets.

#### RED BLOOD CELLS—FOR TRANSPORT

Red blood cells, or **erythrocytes**, have a peculiar shape: they are biconcave disks—meaning that they are concave on both sides (**Figure 2**). The disk shape of erythrocytes is advantageous because it has 20 % to 30 % greater surface area for gas exchange than a sphere of the same volume. Erythrocytes are tiny. Lined up side by side, 135 erythrocytes would measure approximately 1 mm!

The main function of erythrocytes is to carry oxygen from the lungs to the body cells, and to carry carbon dioxide from the body cells back to the lungs to be expelled. Recall from Chapter 10 that oxygen diffuses from the air in the alveoli into the bloodstream. Oxygen attaches to the hemoglobin molecules in the erythrocytes. Oxygen is transported by the erythrocytes around the body and diffuses from the blood into the tissue fluid, and from the tissue fluid into each cell.

**serum** the fluid that results when the cells, platelets, and fibrinogen have been removed from whole blood

**erythrocyte** a red blood cell



**Figure 2** Red blood cells are the most common type of blood cell.

Erythrocytes are formed from stem cells in the marrow of the vertebrae, ribs, breastbone, skull, and bones of the arms and legs. While erythrocytes are developing in the marrow, they have a nucleus. As they mature and are released into the bloodstream, the nucleus breaks down and disappears. This increases the available space for hemoglobin and, in turn, the ability of the erythrocytes to carry oxygen.

Like all cells, erythrocytes eventually die. After about 120 days in circulation, they die and are removed in the liver and spleen. Between 2 million and 3 million erythrocytes are produced each second to replace those that are removed. The appropriate number of erythrocytes in the body is maintained by a feedback system. If the oxygen level in the blood falls below a certain level, the brain signals the production of a hormone, erythropoietin (EPO), in the kidneys. This hormone stimulates the production of additional erythrocytes in bone marrow.

### WHITE BLOOD CELLS—FOR PROTECTION

White blood cells, or **leukocytes**, are also formed in bone marrow. Unlike erythrocytes, there are several different types of leukocytes, all of which have nuclei. Leukocytes are one of the first lines of defence against harmful bacteria, viruses, and other organisms that can cause diseases.

There are two categories of leukocytes—granular and agranular. Granular leukocytes have granules (small particles, or grains) in their cytoplasm. The types of granular leukocytes are neutrophils, eosinophils, and basophils. The granules contain different chemicals that attack foreign material and microorganisms that are brought into the cells. Leukocytes are attracted to the site of an infection or injury and kill bacteria in the area.

Agranular leukocytes, called lymphocytes and monocytes, are specialized for engulfing bacteria and other microorganisms. Some lymphocytes also produce antibodies that attack invading microorganisms or their toxins. Monocytes, which enlarge to become macrophages, are the largest leukocytes and are excellent scavengers. Macrophages clean up bacteria, dead cells, and other debris in the bloodstream and tissues (**Figure 3**).

Many leukocytes use phagocytosis to destroy bacteria or harmful substances. Phagocytosis involves engulfing the bacteria or harmful substance within the cell membrane. Once the cell has engulfed its target, enzymes are released and destroy the target and the leukocyte itself. The remnants of the leukocyte and whatever it engulfed are left behind as a whitish substance known as **pus**. Pus at the site of a cut or other break in the skin, such as a pimple (**Figure 4**), is a sign that your defences are working to combat infection.

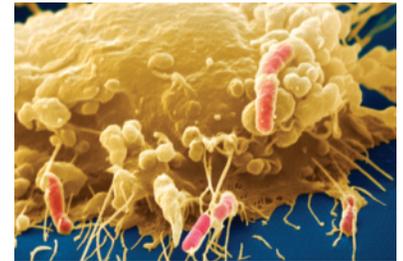
### PLATELETS—FOR PROTECTION

A break in a small blood vessel would be a relatively minor event for the body and would cause a minor bruise. A break in a larger blood vessel might cause an individual to bleed to death if it were not for the blood's second protection mechanism: clotting. **Platelets** are small cell fragments produced from stem cells in bone marrow. Platelets are essential in blood clotting, or coagulation.

When a blood vessel is broken, chemicals in the platelets cause the platelets to stick to collagen fibres in the blood vessel wall. As more and more platelets stick to the fibres, a clot is created to seal the hole in the blood vessel. Once the temporary clot is in place, the clotting process continues below the surface. Fibrinogen in the plasma is converted into long strands of fibrin, forming a mesh that traps more platelets and blood cells (**Figure 5**). This permanent clot stops the leakage of blood and allows time for the injury to heal. Over time, the blood clot is absorbed by the body.

While blood clots are a very important safety feature of the circulatory system, there are some associated risks. A clot that becomes dislodged from the site of an injury can move through the blood vessels and block the flow of blood in some other part of the body. For example, a clot that moves into a blood vessel in the brain and blocks the flow of blood can cause a stroke. Depending on its location in the brain, tissue that has been damaged by lack of oxygen during a stroke can lead to physical and mental disabilities.

**leukocyte** a white blood cell



**Figure 3** Macrophages are very efficient at destroying bacteria.



**Figure 4** A pimple forms when a hair follicle becomes infected.

**pus** a yellowish-white fluid formed in infected tissue, consisting of white blood cells and cellular debris

**platelet** a cell fragment in the blood that is necessary for blood clotting



**Figure 5** A blood clot

**anemia** a condition of a low erythrocyte count or a low hemoglobin level, which leads to low oxygen levels

**CAREER LINK**

**Hematologist**

One of the roles of a hematologist is to analyze complete blood counts or other properties of blood to identify potential diseases or disorders related to the blood. To learn about becoming a hematologist,



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## Counting Blood Cells

If you have ever had a blood sample taken, one of the tests that the doctor likely asked to have performed was the complete blood count, or CBC. A machine called a hemocytometer is used to estimate the number of erythrocytes, leukocytes, and platelets in a particular volume of blood. There is an acceptable or normal range of values for each cell type (**Figure 6**). Values falling outside this range signal that further tests should be done to determine if a medical problem exists. For example, a lower than normal erythrocyte count indicates that a person has a condition known as anemia. The amount of oxygen delivered to the cells is diminished in a person with **anemia**, and he or she may feel tired and run down. Anemia is commonly caused by bleeding from an external injury or from internal bleeding, such as from an ulcer in the stomach. Anemia may result from a variety of diseases, but the most common cause is a deficiency of iron in the diet. Iron in the heme groups enables oxygen to attach to the hemoglobin molecules. 🌐

Components	Relative amounts	Functions
<b>Plasma portion (55 %–58 % of total volume):</b>		
Water	91 %–92 % of plasma volume	Solvent
Plasma proteins (albumin, globulins, fibrinogen, and so on)	7 %–8 %	Defence, clotting, lipid transport, roles in extracellular fluid volume, and so on
Ions, sugars, lipids, amino acids, hormones, vitamins, dissolved gases, urea and uric acid (metabolic wastes)	1 %–2 %	Roles in extracellular fluid volume, pH, eliminating waste products, and so on
<b>Cellular portion (42 %–45 % of total volume):</b>		
Platelets	250 000–300 000 per microlitre	Roles in clotting
Leukocytes (white blood cells) Neutrophils Lymphocytes Monocytes/macrophages Eosinophils Basophils	3000–6750 1000–2700 150–720 100–360 25–90	Phagocytosis during inflammation Immune response Phagocytosis in all defence responses Defence against parasitic worms Secrete substances for inflammatory response and for fat removal from blood
Erythrocytes (red blood cells)	4 800 000–5 400 000	Oxygen, carbon dioxide transport

**Figure 6** Each component of blood has an acceptable range of values representing its proportion of the total volume. Each blood cell type has a normal range of numbers. The various components of the blood have specific functions.

A higher than normal leukocyte count is a sign that the body is fighting an infection. It is also one of the symptoms of leukemia, a form of cancer of the blood and bone marrow. In this disease the cancerous leukocytes grow and survive better than normal cells and interfere with the production of other leukocytes, erythrocytes, and platelets.

## Blood Types

Blood transfusions are common and reasonably safe procedures today, but it was not always so. The first blood transfusions did not have a very high success rate; some patients recovered without any ill effects, whereas others died. The reason for the deaths was not understood until 1901, when Karl Landsteiner discovered that there were different blood types and that some types were incompatible. Successful transfusions depend on proper matching of the blood types.

Recall from Chapter 5 that there are four blood types: type A, type B, type AB, and type O. Blood types are determined by the presence (or absence) of different sugars, called markers, on the cell membranes of erythrocytes. There are two markers: A and B. Type A blood has the A marker, and type B blood has the B marker. Individuals with both markers present have type AB blood, and individuals with neither marker have type O blood.

Incompatibility occurs because the markers act as antigens, which are considered foreign material. When the immune system detects antigens, it produces antibodies that attach to the antigens. This causes the blood cells to clump together, blocking blood vessels and preventing the circulation of blood and delivery of oxygen. For example, if type A blood is transfused into a person with type B blood, the recipient will develop antibodies in response to the type A marker. Type A blood can be transfused into a person with type A or type AB blood because their blood already has the A marker and will not produce antibodies against it.

Because type O blood has neither marker, transfusion of type A, B, or AB blood into an individual with type O blood will induce an antibody response. People with type O can receive only type O blood. However, because it has no markers, type O blood can be transfused into individuals of any blood type. A person with type O is said to be a universal donor.

Type AB is the opposite of type O; it has both protein markers and is compatible with any type of donated blood. A person with type AB is known as a universal recipient. However, type AB blood can only be transfused to another type AB person.

You learned in Chapter 5 that blood type is an inherited trait. However, this does not mean that your blood type is automatically compatible with your parents' blood type. Depending on their blood type, you may be able to donate or receive blood from one, both, or neither of your parents. 

## The Rhesus Factor

There is another inherited factor, called the rhesus factor, which affects the compatibility of blood types. The rhesus factor was discovered by studying the blood of rhesus monkeys. The rhesus factor is an antigen on erythrocyte membranes that produces an antibody reaction. This is not as severe as the antibody reaction to blood type markers. The rhesus antigen is present in approximately 85 % of the population, and these individuals are said to be Rh-positive. In the remaining 15 % of the population, the rhesus antigen is not present, and these individuals are referred to as Rh-negative. Individuals with Rh-negative blood may donate their blood to, but should not receive blood from, individuals with Rh-positive blood. It is always best to mix blood of the same type and rhesus factor. 

## Blood Substitutes and Artificial Blood

During emergencies when blood transfusions are needed, the supply of blood may not always be adequate or totally safe. Researchers are attempting to develop a blood substitute that will solve these problems. Most of the research is focused on the transport function of blood, that is, its ability to carry oxygen and carbon dioxide, rather than on the more complex protection roles of blood. An ideal blood substitute must

- not induce an antibody reaction in the recipient
- eliminate, or greatly reduce, the possibility of transmitting infections
- be capable of delivering adequate oxygen
- be readily available, capable of being stored at room temperature, and have a long shelf life

Including all of these qualities make the task of developing a blood substitute very challenging, and there has been limited success to date.

### WEB LINK

For more information on different blood types and blood transfusions,



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### WEB LINK

To learn more about the discovery of the rhesus factor, and the role of the rhesus monkey,



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Research has focused on two types of artificial blood: hemoglobin-based oxygen carriers (HBOCs) and perfluorocarbon emulsions (PFCEs). HBOCs may contain human or cow blood. The problem with using HBOCs is that hemoglobin has a toxic effect on the kidneys when it is outside the protective environment of erythrocytes. PFCEs are totally synthetic. Fluosol, a PFCE-based product, was the first and only artificial blood approved for medical use. However, because there were some adverse effects and the results were marginal, it was removed from the market in 1994. Although Fluosol was not successful, research continues in the field of PFCEs.

## UNIT TASK BOOKMARK

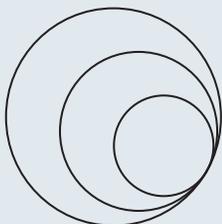
Consider what you have learned about blood, in particular blood cell count. How can this information help you as you complete the Unit Task?

## 11.2 Summary

- The main components of blood are plasma and the cellular component, which includes red and white blood cells and platelets.
- The primary function of red blood cells, or erythrocytes, is to transport oxygen. Erythrocytes contain hemoglobin, which increases the amount of oxygen that can be carried in the blood. White blood cells, or leukocytes, are an important part of the immune system. Platelets initiate blood clotting.
- The proportion of each component and the number of each type of cell in a specific volume of blood should fall within an acceptable range. Values outside this range may indicate a health problem.
- Blood type incompatibility occurs when the donor blood has a marker but the recipient blood does not. The marker induces an antibody reaction in the recipient's blood.
- A person with blood type O is a universal donor, and a person with blood type AB is a universal recipient.
- The rhesus, or Rh, factor is an antigen that also affects compatibility. Rh-positive individuals carry the antigen; Rh-negative individuals do not.
- Research is being conducted in developing a product that can carry out the oxygenation function of red blood cells.

## 11.2 Questions

- (a) What are the two main functions of blood?  
(b) Create a table or other graphic organizer to describe the components of blood and their functions. **K/U C**
- How are erythrocytes different from other cells of the body? **K/U**
- Create a diagram like the one shown in **Figure 7** and apply the following labels: serum, blood, plasma. Explain your choices. **K/U T/I C**
- Describe the process of blood clotting. What risk is associated with blood clotting? **K/U**
- What information is provided in a complete blood count? How can this information be used? **K/U A**
- Emergency vehicles may carry O-negative blood for use at the scene of an accident. Explain why this is a common practice. **K/U T/I A**
- Create a table or use a graphic organizer to summarize the compatibility of each ABO blood type and rhesus factor with other blood types. **K/U C**
- (a) How is artificial blood different from real blood?  
(b) What are the advantages of artificial blood over real blood? **K/U A**
- Another approach to solving the problem of available blood for transfusion is called “antigen camouflaging.” Use the Internet and other sources to research antigen camouflaging. Write a report describing how antigen camouflaging works and what advantages it has over artificial blood. **T/I C**
- Use the Internet and other sources to research available blood substitutes and the Canadian position on them. What are the major stumbling blocks to approval in Canada? **T/I A**



**Figure 7**



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